Section 3 Interpretation and Results

3.1 Slice Map Analysis

GPR slice maps are a three-dimensional tool for imaging radar reflection amplitudes across an axial plane at various depth intervals. Slice maps can essentially be thought of as a GPR plan-view of the survey area. By combining and interpolating transect profiles in a plan view, slice maps give shape to anomalous signal returns that extend into multiple profiles. During this project slice maps were primarily used to locate linear features (utilities or trenches associated with utilities). Pit features, and discrete objects were not clearly identified on slice maps for the Section 4 project area due to the high level of disturbance associated with urban development and the relatively shallow depth of GPR signal penetration (.70 mbs–1.0 mbs). Cultural deposits were generally located deeper than a m for Section 4.

For this project, slice maps were generated in *Radan* 7 using Color Table 1 which is able to display very subtle changes in reflectivity as well as highly contrasting reflection transitions. Figure 4 is an annotated example of a GPR slice map used for this project and a guide for interpretation.

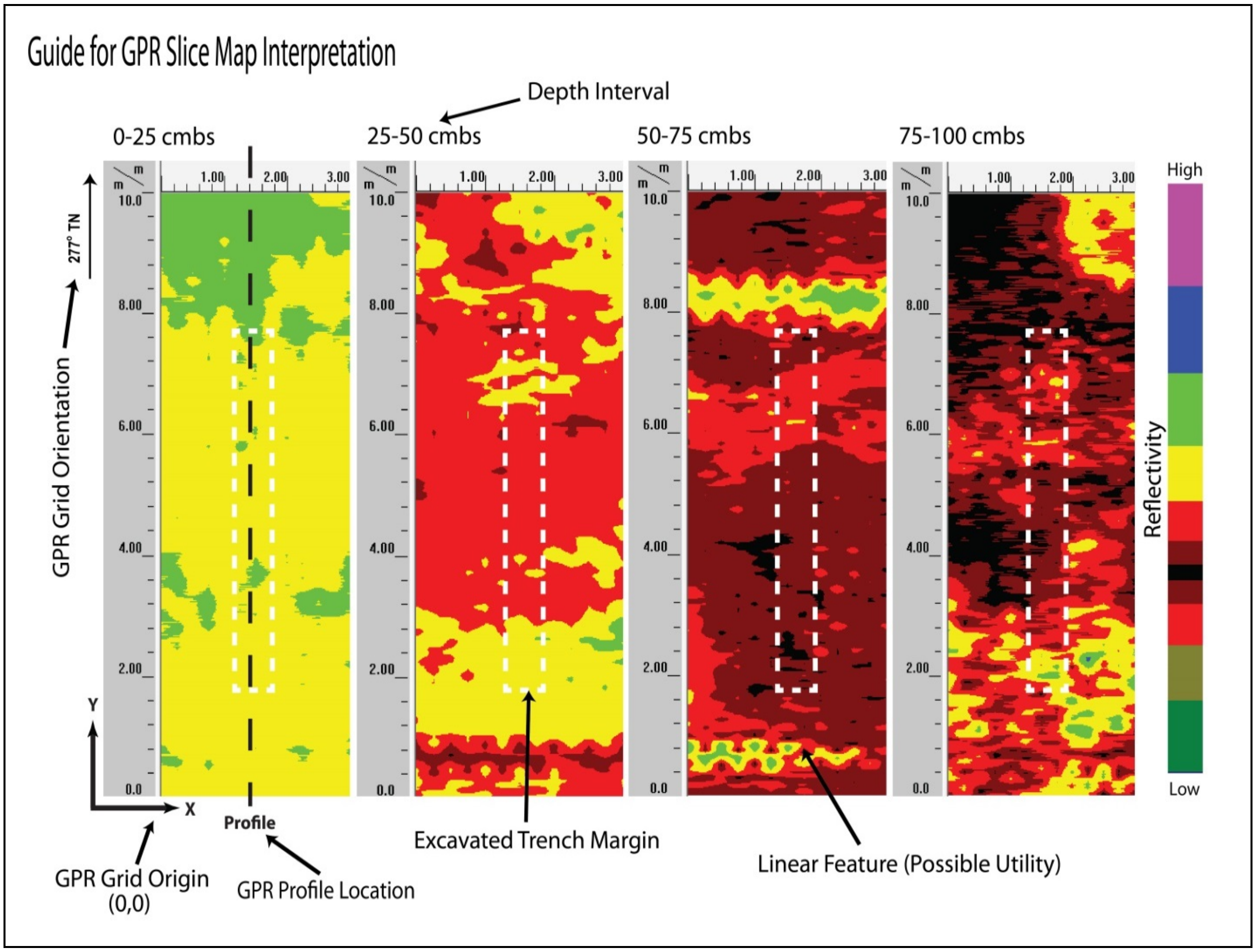

Figure 4. Guide for GPR Slice Map Interpretation

3.2 Profile Analysis

Following post-processing, interpretation of GPR profiles began with locating and identifying reflection interfaces. It was important to determine if changes in reflectivity represent actual subsurface transitions/features or signal interferences. Interferences in signal return can result from random electromagnetic noise (i.e., cellular devices and ELF emissions from power lines), harmonic signal resonance, standing surface water, etc. Signal interference can take the visual form of regularly repeating reflections or random noise that will display a “digitized” or discontinuous look on the GPR profiles. Transmitted signals can also harmonically resonate, which will cause repeating signal horizons and false increases in reflectivity. Harmonic resonance is often caused by the transmitted signal encountering a metal object creating a “ringing” effect. Rough surface topography can also cause the GPR antennae to lose contact or “uncouple” the transmitted signal from the surface effectively scattering the signal. Examples of signal interference can be seen at the bottom of Figure 5. Signal filters can be applied to remove interference during post-processing but should be kept to a minimum to avoid losing subtle signal changes that can offer information. Once the determination of clean signal versus interference had been made, GPR profile analysis for this project was approached in three ways: locating signals representing discrete subsurface objects, identifying sediment material based on reflectivity and signal texture, and determining stratigraphy based on reflectivity transitions.

3.2.1 Discrete Objects

The reflected signal generated by a discrete buried object is generally hyperbolic in form. The apex, or top of a hyperbola, represents the origin of the object. In general, larger objects form larger hyperbolas and the width of the hyperbolic apex is relative to the diam or width of the object. This method of analysis is used to locate utilities, cultural deposits, building structures, etc. It is important to consider the data collection transect orientation and spacing carefully when applying this method. Objects that are located between collection interval lines may be missed or misread. Features that are aligned parallel to the collected signal transect will form continuous horizontal reflections. For instance, a pipe that runs parallel to the collected transect will appear as a horizontal line on the GPR profile. That is why it was important to collect data in both X- and Y-directions in the event that a liner object, such as a pipe, was located between the transect intervals. A good example of a hyperbolic reflection created by a discrete object (utility pipe) is located on Figure 5.

During Section 4 of the HHCTCP, discrete objects observed in the GPR data and subsequent excavations were generally limited to objects associated with utilities. The only culturally significant discrete objects encountered during test excavations that were large enough to detect with the GPR was a buried stone and mortar wall observed in T-119 and T-119A and a privy located in T-202. Unfortunately the GPR was not able to clearly resolve these objects. The privy was beyond the range of clean signal return and the stone and mortar walls were only partially in range and located under a concrete slab. No other cultural deposits or subsurface archaeological features were identified by the GPR survey.

GPR Slice maps and profiles were combined in a statistical study to determine the accuracy of locating discrete objects. As mentioned, the only discrete objects that displayed clear discernible reflections were objects associated with utilities. The study found that out of the combined 498 profiles and slice maps, 213 contained utilities that were ground-truthed by excavation. Forty-seven percent of these excavations showed a clear signal in the GPR data that corresponded to the utility. Fifty-four percent of the utilities encountered during these excavations did not display a clear signal response in the GPR analysis. Factors that contributed to the low level of detection include depth of utility located beyond the GPR “visibility” range, no clear sediment transition associated with the utility, and difficulty to discern very shallow utilities in highly compacted sediments.

3.2.2 Human Burials

Part of this study was designed to determine the effectiveness of locating human burials with GPR technology. Burials can be considered discrete objects with stratigraphic and sediment transitions associated with burial pit features. A total of 7 test excavations contained human remains in Section 4. Most of the remains consisted of a single bone or fragment and were too small to be discerned by the GPR. Three test excavations (T-142, T-226C and 227A) contained *in-situ,* articulated burials. The burials in T-226C and T-227A were both located deeper than the range of clean signal return and could not be clearly resolved during processing. Unfortunately no distinct signal response could be directly attributed to the burials. The burials were located in naturally deposited Jaucas sand and presumed to be in the flexed position. This would imply that the burial was likely pre-Contact with no coffin. It has been the experience of the CSH GPR team that pre-Contact remains buried in Jaucas sand with no associated coffin are very difficult to observe in the GPR data. Factors inhibiting results may include similarities in chemical composition of the sand and human bone, very little change in compaction and sediment material associated with sand burial, and lack of grave goods or coffins that reflect the signal. A detailed description of each test excavation that contained human remains is provided following the Summary section of this report.

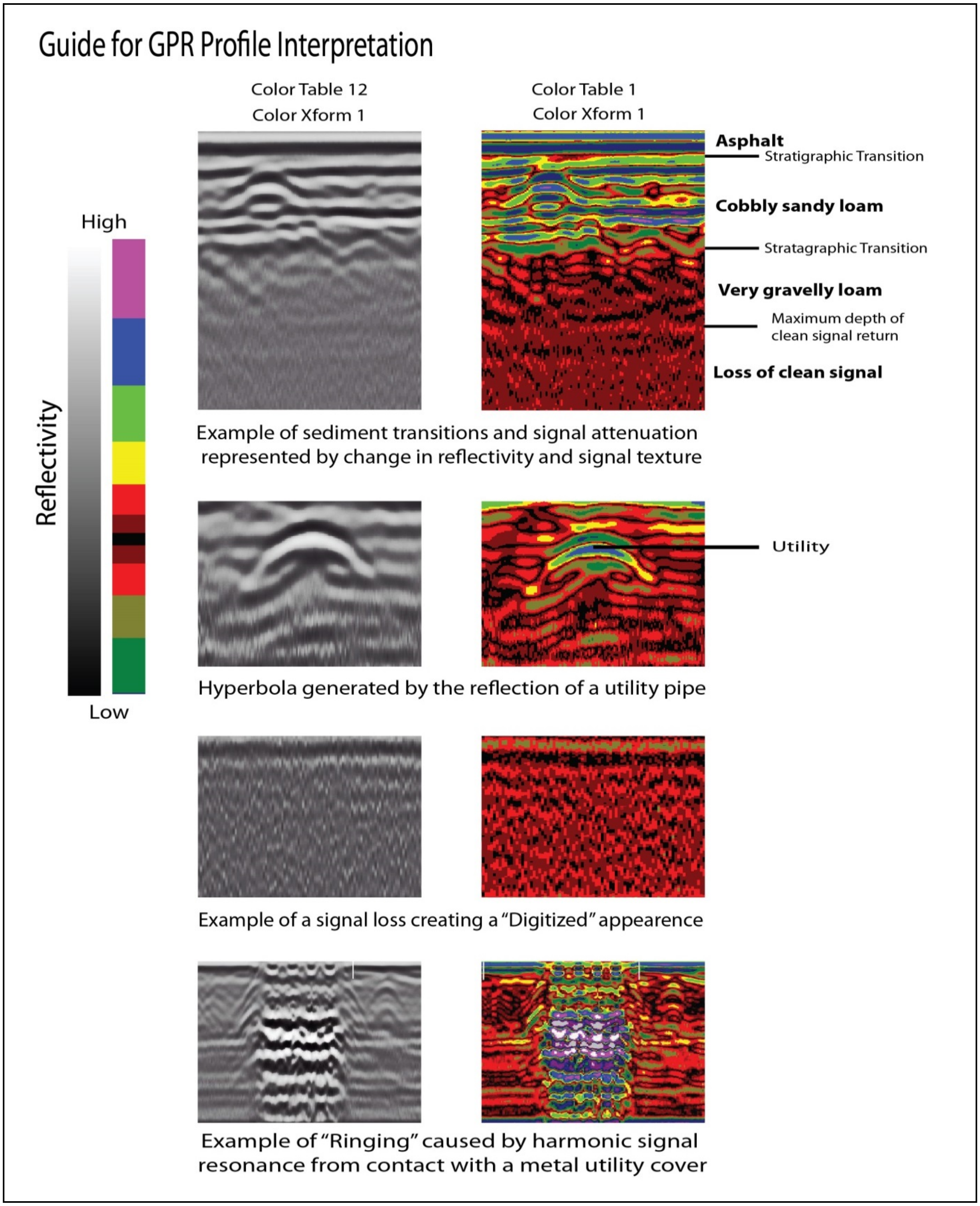

Figure 5. Guide for GPR Profile Interpretation

3.2.3 Sediments

GPR data can be used as a non-invasive method to determine subsurface sedimentation based on signal reflectivity and texture. Signal reflectivity is affected by variations in material density, compaction, geochemistry of sediment material, water content, etc. These factors ultimately determine material conductivity and signal attenuation. Less conductive materials like sand or gravel have a greater degree of reflectivity. Conductive materials like silt or clays attenuate the transmitted signal and are less reflective. Signal texture is a way to describe signal patterns created by changes in signal shape and reflectivity.

A goal of this study was to analyze methods of using GPR analysis as a non-invasive way to locate naturally deposited sediments in the project area and use this information to determine probability of encountering subsurface cultural deposits. Section 4 of the HHCTCP was dominated by historic fill events which capped, truncated, or replaced naturally deposited sediments. *In situ*, undisturbed sand deposits and cultural layers were encountered during this Section of the project. However, most naturally deposited sediment types observed during Section 4 were located below the maximum depth of clean GPR signal return. The maximum depth of clean signal return for the Section 4 project area averaged between 0.75 and 1.0 mbs. This signal “visibility” corroborates with the USDA GPR suitability rating of low to very low for this area. The water table was also located beyond this range in every excavation.

Figure 6 displays the types of naturally deposited sediments that were encountered during Section 4 excavations within the zone of clean signal return. The results of the study showed that sandy sediments displayed higher reflectivity and wavy signal topography. Jaucas sand, which is naturally deposited and has a higher probability of containing cultural deposits, is highly reflective with rounded, undulating signal topography (Figure 6). Sediments rich in clay or silt generally displayed lower reflectivity with smooth signal topography. Sediments with high percentages of gravel to cobble inclusions were indicated by multiple small hyperbolas, which are best observed in Color Table 12 profiles. Detecting the coral shelf was difficult due to highly variable nature of coral polyp growth and density. Generally speaking though, coral shelf displayed low reflectivity and wavy signal topography. Included in the excavation by excavation analysis sections following the summary, are figures displaying signal textures representing sediments from each of the 11 geographic zones.

Recognition of patterns in signal texture and reflectivity requires a great deal of experience and can be somewhat subjective in nature. While clear patterns are emerging from the results of this survey, it is difficult to quantitatively assess accuracy of this method. Using GPR analysis for determination of sediment material should be viewed as an approximation but when coupling the GPR data with soil surveys and results from previous archaeological research in the vicinity of a project area, useful information on sedimentation for a project area can be attained in a non-invasive way.

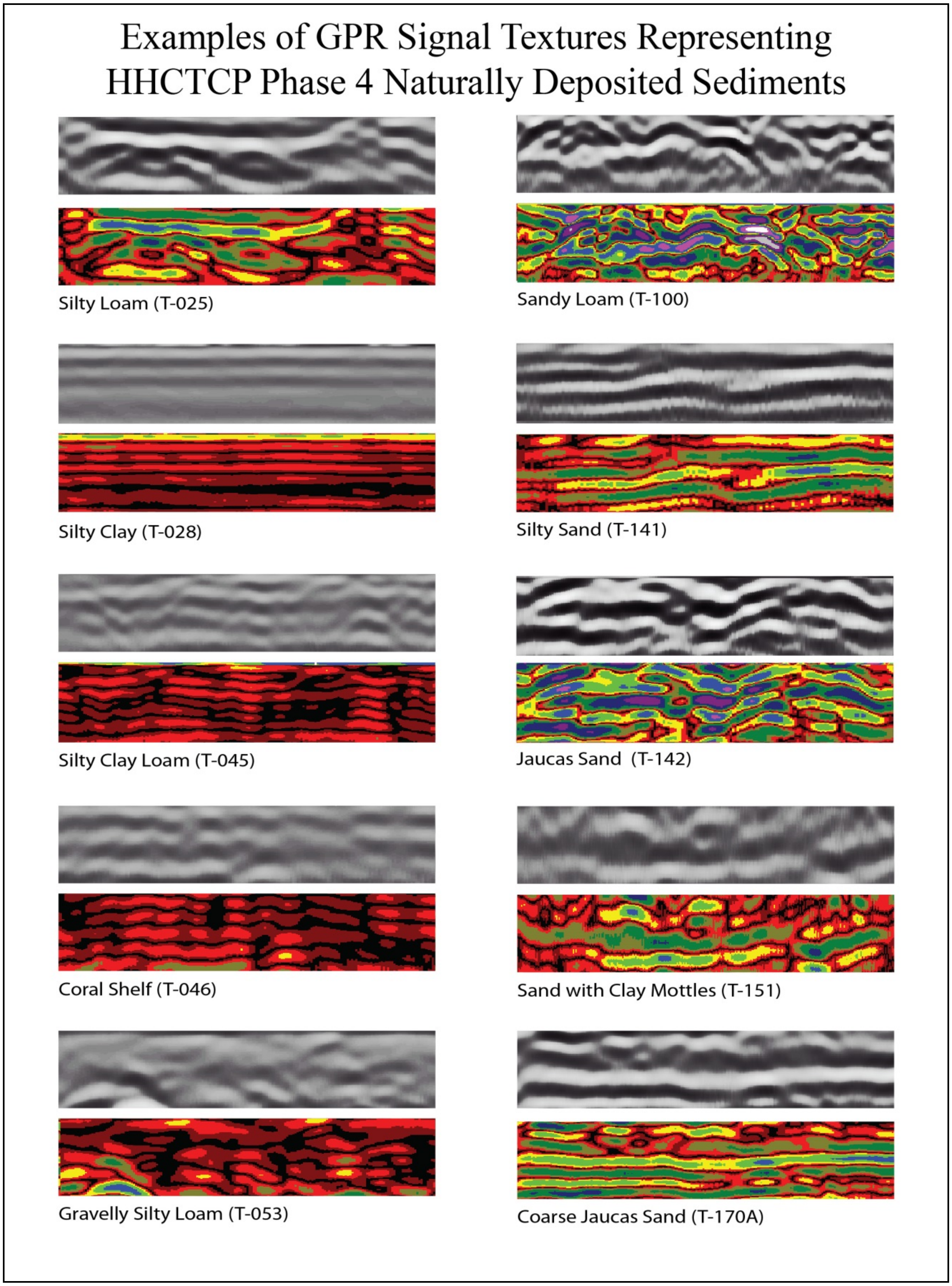

Figure 6. Examples of GPR Signal Textures Representing HHCTCP Section 4 Naturally Deposited Sediments

3.2.4 Stratigraphy

In recent years, GPR analysis is developing into a method for determining subsurface stratigraphic sequences by analyzing changes in signal reflectivity. Stratigraphic transitions can be represented by abrupt changes in reflectivity. These changes are often in the form of horizontal banding sequences as observed in the GPR profiles. As previously stated, signal transitions can be caused by variations in material density, compaction, geochemistry of sediment material, water content, etc. Figure 5 shows two distinct stratigraphic transitions based on reflectivity and horizontal banding. The first transition occurs directly below the top layer of the highly reflective asphalt. A second transition is observed bounding the higher reflectivity “cobbly sandy loam” and lower reflectivity “very gravelly loam.” GPR data is also useful for locating vertical or cross-cutting stratigraphic transitions, such as utility excavations or vertical sediment truncations.

Using GPR data as a non-invasive means of stratigraphic sequencing can aide in determining the relative chronology of sediment deposition within a project area. This method of analysis can be coupled with GPR sediment analysis to determine the probability of encountering natural sedimentation in a project area. In urban areas, several stratigraphic layers could imply multiple depositional fill events associated with historic land use. A project area multiple fill events may lower the probability of encountering well preserved *in situ* natural deposits.

3.3 Excavated Profile and GPR Profile Visual Comparison

As a way of testing the ability of GPR to discern subsurface stratigraphy in the project area, a visual comparison between the GPR profile and the stratigraphic profile for each test excavation was conducted. Excavation profiles were aligned by orientation and adjusted to the same vertical and horizontal scale as the GPR profiles for each excavation. In some cases it was necessary to mirror the drafted profile to match the orientation of the GPR Profile. It was not possible to match collected GPR transects to the exact excavated profile location because of the variant nature of choosing which sidewall to draft following excavation and GPR transect interval spacing. As a result, GPR profiles were chosen based on proximity to the center of the test excavation, in essence creating an averaging effect for interpretation. The GPR profiles were generated in *Radan 7* using Color Tables 1 and 12 (Figure 5). Color Table 1 is very effective in displaying subtle changes in signal reflectivity which helps to distinguish sediment transitions. Color Table 12 is a universally recognized color scheme and better at distinguishing hyperbolic reflections associated with discrete objects.

Visually comparing the Section 4 GPR profiles with the excavated profiles reveals an overall strong correlation between changes in GPR signal reflectivity and “ground-truthed” stratigraphy for the project area. Comparisons only considered stratigraphic transitions within the range of clean signal return (0.70–1.0 mbs). Stratigraphic layers with a thickness of less than 0.10 m were not considered due to the difficulty of visually resolving them on the GPR profiles. The results of the visual comparison were divided into three levels of correlation for each excavation: strong, moderate, and weak. A strong visual correlation suggests that all stratigraphic transitions confirmed by excavation were observed on the GPR profile. Stratigraphic transitions were required to be within 0.15 mbs of the ground-truthed origin. 47 percent (85/249) of the excavations for Section 4 show a strong correlation with the GPR results. Moderate correlations suggest that most stratigraphic transitions are observed in the GPR profile. Stratigraphic transitions were required to be within 0.25 mbs of the ground-truthed origin. 35 percent (85/249) of the excavations for Section 4 show a moderate correlation with GPR results. A weak visual correlation suggests that very few to no stratigraphic transitions confirmed by excavation were observed on the GPR profile. Stratigraphic transitions were required to be within 0.50 mbs of the ground-truthed origin. 18 percent (46/249) of the excavations for Section 4 show a weak correlation with GPR results.